Annulus Formation on Otoliths and Growth of Young Summer Flounder from Pamlico Sound, North Carolina[1]

ALLYN B. POWELL

National Marine Fisheries Service
Southeast Fisheries Center, Beaufort Laboratory
Beaufort, North Carolina 28516-9722

Abstract

Summer flounder *Paralichthys dentatus* were collected monthly in Pamlico Sound, North Carolina, and adjacent waters from May 1971 to July 1972 to determine age at first annulus (opaque ring) formation on otoliths and to estimate growth of young-of-the-year and yearling fish. The first annulus formed on yearling otoliths between January and June. It often becomes obscure as fish age, making fish older than 2 years difficult to age from otoliths. A von Bertalanffy equation with a seasonally varying coefficient closely modeled summer flounder growth during a cohort's first 17 months:

$$L(t) = L_{max} - (L_{max} - L_{min})\exp\langle -at - 6a/\pi\{\cos[\pi\theta/6] - \cos[\pi(t + \theta)/6]\}\rangle;$$

L_{max} (315.8 mm) is maximum body size; L_{min} (14.4 mm) is size at estuarine immigration; t is age in months; a (0.059) and θ (−3.347) are parameters describing seasonal change in the von Bertalanffy coefficient. Mean total length at the end of the first year was 167 mm for males and 171 mm for females, and differences between sexes were not significant ($P = 0.24$). After fish moved into the estuary in February, their body weight increased at an estimated 5% per day, but growth rates declined over the following months even as water temperatures increased, and by late fall growth was negligible.

The summer flounder *Paralichthys dentatus* is valuable to both commercial and recreational fisherman from Cape Cod, Massachusetts to Cape Lookout, North Carolina. In North Carolina, the leading state in landings, approximately 4,600 t, valued at approximately 3.5 million dollars, were landed during the 1980–1981 winter trawl fishery (Kenneth Harris, personal communication). An assessment of the fishery has not been accomplished.

I examined otoliths to determine the age and time of year the first opaque ring appears. From the collections I also was able to determine the size of male and female fish after their first year of life and monthly growth rates of young-of-the-year and yearlings in estuaries.

Previous age-and-growth estimates for summer flounder, necessary for a valid assessment of the fishery, are inconsistent because investigators disagreed as to the age when the first annulus (opaque ring) forms on otoliths. Poole

(1961) considered the first opaque ring on otoliths a first annulus, but Smith and Daiber (1977) considered it a second. Eldridge (1962) suggested that the first opaque ring formed at the end of the fish's third year of life. Young-of-the-year and yearling fish could have been used to resolve this conflict, but none were available to those investigators. I collected large numbers of both age groups and limited numbers of older fish from Pamlico Sound, North Carolina to resolve this problem and also to estimate growth rates. Growth rates are needed to compute production and can provide information on how ecological variations within estuaries affect growth processes (Pearcy 1962).

Methods

Summer flounder were collected monthly from May 1971 through July 1972 by otter trawl in Pamlico Sound and adjacent waters as described in Powell and Schwartz (1977). After being cleared in glycerin, otoliths were read under reflected light. Measurements were taken only on the left otolith, as the left and right otoliths are asymmetrical in relation to the focus. Radii were measured with an ocular mi-

crometer to the nearest 0.1 mm from the focus to the anterior edge of the otolith and to each opaque ring.

Ages were arbitrarily advanced one year on January 1. Young-of-the-year fish in December, therefore, became yearlings in January. This anniversary date coincides with spawning (Poole 1966; Smith 1973) and the commencement of opaque ring formation (Table 1).

Lengths were back-calculated by the Lee method (Tesch 1968). An analysis of covariance determined that the relationship between total length (TL) in mm and otolith radius (OR) in mm differed significantly ($P < 0.001$) between sexes:

$$TL \; ♀ = -61.8 + 88.300 \; (OR), N = 318;$$
$$TL \; ♂ = -33.4 + 77.809 \; (OR), N = 239.$$

Therefore different correction factors (length intercepts) were used for back-calculations for males and females. In certain analyses, only females were used, because few older males were collected.

Results and Discussion

Annulus Formation

To determine the age when the first annulus forms, I examined otoliths from fish that were known to be either young-of-the-year, yearlings, or older. These age groups were readily identified from length-frequency distributions (Fig. 1).

An annulus was observed on yearling otoliths about 2.7 mm from the focus. The annulus first appeared as an opaque check on the anterior edge of the otolith between January and May (Table 1), but did not appear as a complete ring until late summer. I considered this check, no matter how small, to be an annulus.

The percentage of yearlings with an annulus increased progressively each month (Fig. 1). Only 12% had an annulus in January, 50% in March, 93% in May, and 100% in June. Because an annulus was present on virtually all fish after May (two yearlings in December did not have an apparent annulus: Fig. 1), I conclude that an annulus forms on all yearling summer flounder.

I analyzed distributions of back-calculated lengths from older fish to determine if annuli observed on yearling otoliths persist as the fish ages. If the first annulus does become obscure,
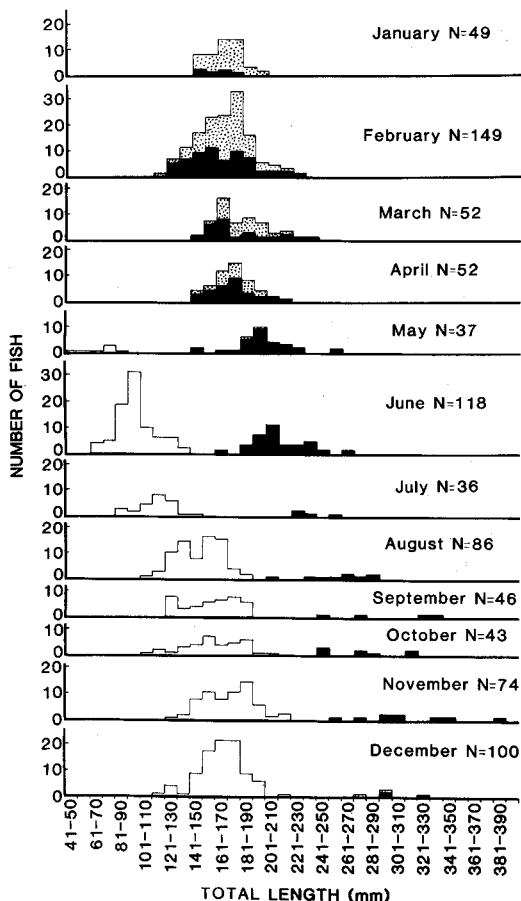

FIGURE 1.—*Monthly length-frequencies of young-of-the-year (unshaded) and yearling summer flounder. Yearlings without an opaque ring on their otolith are shown stippled, those with an opaque ring are solid black.*

lengths back-calculated from older fish should be significantly different from those calculated from yearlings, and a distribution of those lengths should depict the modal length of summer flounder at age 2.

The evidence suggests that the first annulus may become obscure, though not consistently. The mean length at time of first annulus formation calculated for yearlings was significantly different from that calculated for older fish ($P = 0.004$), but the lengths calculated from older fish were spread over a wide range and no mode was apparent (Fig. 2). In addition, lengths back-calculated to the time of second and third annulus formation were highly variable (Fig. 2).

Smith and Daiber (1977) concluded, for fish

TABLE 1.—*Monthly frequency distributions of the distance from the anterior edge of the first opaque ring to the anterior edge of the otolith (marginal increment) on yearling summer flounder otoliths (1 unit = 0.0712 mm). Values are numbers of fish.*

Month	Total number	Marginal increment (units)				
		0	1–3	4–6	7–9	≥10
Jan	6	2	3	1		
Feb	59	15	41	1	2	
Mar	26	13	13			
Apr	29	12	17			
May	24	1	18	5		
Jun	29	5	12	8	4	
Jul	4				1	3
Aug	7					7
Sep	2					2
Oct	6					6
Nov	3					3
Dec	3					3

collected in Delaware Bay, that the first opaque ring was deposited on otoliths at age 2. Shepherd (1980), using scales and fin rays of fish collected in Massachusetts, agreed with this conclusion. The difference between my results and theirs could be due to geographic differences between summer flounder stocks; two populations have been identified, one north and one south of Cape Hatteras, North Carolina (Wilk et al. 1980). Young of both populations, however, utilize Pamlico Sound as a nursery area and do not return to their areas of origin until they are yearlings (Wilk et al. 1980). Therefore, the annuli I observed for yearlings should appear on otoliths of older fish from both northern and southern populations unless they become obscure as the fish age. I believe the indistinctness of first annuli on older otoliths is the explanation for discrepancies among studies, based on the variability in back-calculated lengths of older fish that I found (Fig. 2). Additional problems could be caused by inaccurate measurements of opaque rings, which usually are diffuse or distorted at the anterior end where measurements are made, or obscured by otolith centers. Shepherd (1980) reached similar conclusions.

The conflict between Poole (1961), who considered the first opaque ring a yearling annulus, and Smith and Daiber (1977) who considered it an age-2 annulus, can be resolved if Poole's ages are advanced 1 year. The first opaque ring Poole (1961) observed on otoliths of New York adults was probably the second annulus. Total lengths he observed at "first" an-
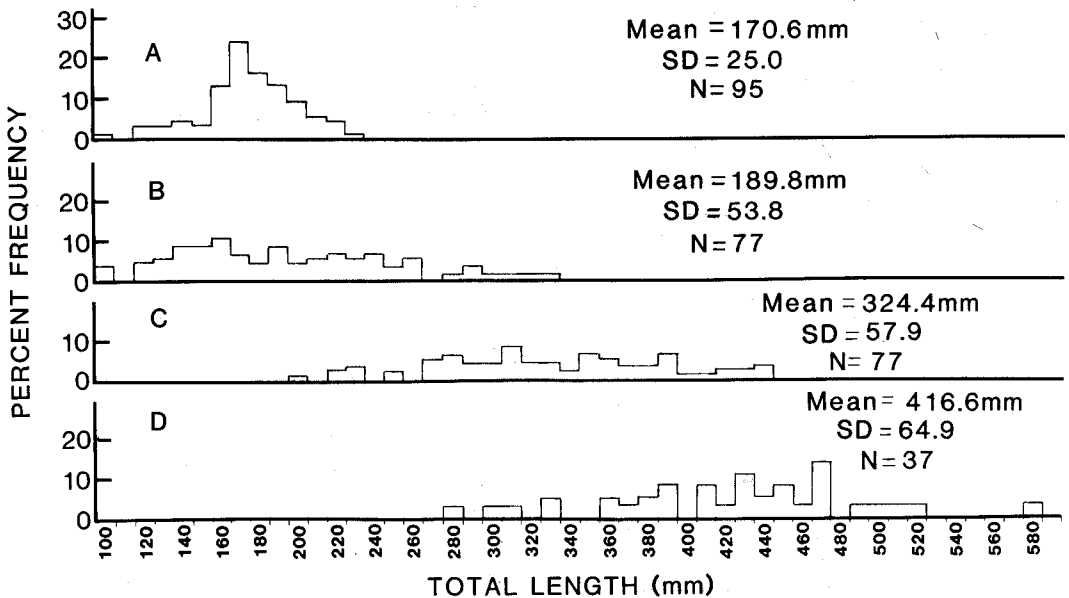

FIGURE 2.—*Back-calculated length-frequency distributions of female summer flounder: **A**, to the first opaque ring from yearlings; **B**, to the first opaque ring from fish with more than one opaque ring; **C**, to the second opaque ring; **D**, to the third opaque ring.*

nulus formation (about 250–270 mm) are close to Smith's and Daiber's "age-2" lengths, and greater than yearling lengths that both Eldridge (1962) and I found.

The use of other bony parts to accurately age summer flounder must be assessed. Although some investigators could not find annuli on summer flounder scales (Poole 1961; Powell 1974), Shepherd (1980) recently observed distinct annulus-like marks on impressions of scales made in laminated plastic. With this technique, scales may be useable. They are easily obtained and the problems presented by otoliths are avoided.

Growth

Mean total lengths at time of first annulus formation, back-calculated from yearlings, were not significantly different for males and females ($P = 0.024$): 166.5 mm ($N = 92$) and 170.6 mm ($N = 95$), respectively. These are valid estimates because annulus formation occurs when growth is negligible (Fig. 1). Agreement was good between back-calculated lengths and empirical lengths of yearling fish captured from January to March (Fig. 3).

Monthly growth was described for the period that summer flounder utilize Pamlico Sound and adjacent estuarine waters as nursery areas. Because maximum spawning occurs in December (Smith 1973) and maximum movement into the estuary occurs in February (Williams and Deubler 1968; Lewis and Mann 1971), I estimated the age at the onset of estuarine residence in February to be 2 months. The size of fish at that time was estimated from 76 fish collected with a modified neuston net (Hettler 1979) at the entrance of the Newport River estuary near Beaufort, North Carolina. Young-of-the-year from Pamlico Sound were first collected in May 1971. Mean monthly lengths were calculated from fish collected from then through July 1972 (1971 year class).

Monthly growth from February 1971 through July 1972 was described by a modified von Bertalanffy equation with a seasonally varying coefficient (Cloern and Nichols 1978):

$$L(t) = L_{max} - (L_{max} - L_{min})$$
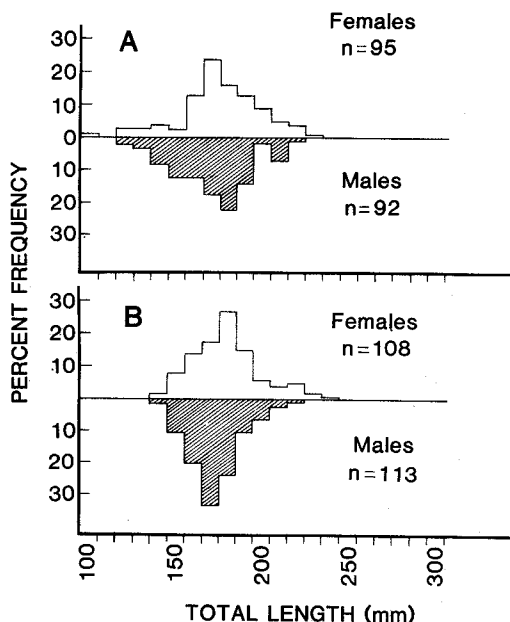$$\cdot \exp\left\{-at - \frac{6a}{\pi}\left[\cos\frac{\pi\theta}{6} - \cos\frac{\pi(t + \theta)}{6}\right]\right\};$$

FIGURE 3.—*The size at first opaque ring formation of summer flounder as shown by calculated and empirical length-frequency distributions:* **A**, *back-calculated lengths to the first opaque ring from yearlings;* **B**, *empirical lengths of yearlings captured from January to March.*

L_{max} (315.8 mm) is maximum body size; L_{min} (14.4 mm) is size at estuarine immigration; t is age in months; a (0.059) and θ (−3.347) are parameters, estimated by least squares regression, that describe the seasonal change in the von Bertalanffy coefficient. The von Bertalanffy growth model with a seasonally varying coefficient provided a good description of summer flounder growth (Fig. 4). It is appropriate because it accounts for seasonal variation in growth due to temporal changes in water temperature and seasonal variations in prey quantity and quality (Cloern and Nichols 1978). This model was used also to calculate daily instantaneous rates of increase in length (G_L) (Ricker 1975):

$$G_L = \frac{\text{Log}_e L_i - \text{Log}_e L_{i-1}}{t}$$

where L_i = total length at age i (in months) and t = time interval (30 days). Monthly lengths were estimated from the von Bertalanffy equation, rather than empirically (Table 2), because the equation provided a smooth curve of average growth in length. Values of G_L were converted to instantaneous rates of increase in weight (G;
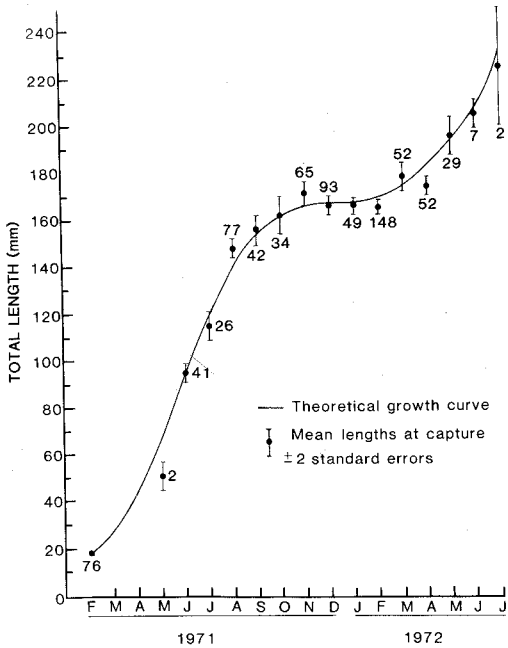
FIGURE 4.—*Theoretical growth of young-of-the-year and yearling summer flounder from Pamlico Sound, North Carolina and adjacent estuarine waters, described by a modified von Bertalanffy equation. Numbers along the curve are sample sizes.*

TABLE 2.—*Mean monthly total lengths at capture (TL) ± 2 SE, total lengths estimated from a modified von Bertalanffy equation (TLe) and daily instantaneous growth rate by weight (G) of young-of-the-year and yearling summer flounder during their estuarine residency, 1971–1972. Dashes indicate no data available.*

Month	Age (months)	TL (mm)	N	TLe (mm)	G
Feb	2	17.9 ± 0.4	76	17.9	0.046
Mar	3	—	—	27.9	0.051
Apr	4	—	—	45.6	0.043
May	5	51.0 ± 6.0	2	69.4	0.033
Jun	6	94.8 ± 3.9	41	95.4	0.023
Jul	7	115.1 ± 5.5	26	119.7	0.016
Aug	8	148.2 ± 4.0	77	139.6	0.010
Sep	9	156.3 ± 6.4	42	153.8	0.006
Oct	10	161.9 ± 8.1	34	162.4	0.002
Nov	11	170.9 ± 4.8	65	166.3	0.001
Dec	12	165.6 ± 3.7	93	167.3	0.000
Jan	13	166.3 ± 3.6	49	167.4	0.001
Feb	14	165.0 ± 3.4	148	169.0	0.003
Mar	15	177.6 ± 5.7	52	173.9	0.005
Apr	16	174.0 ± 4.3	52	182.6	0.006
May	17	195.1 ± 8.0	29	194.3	0.007
Jun	18	203.8 ± 6.4	7	207.1	0.006
Jul	19	223.5 ± 25.4	2	219.1	

Table 2) from the relationship $G = bG_L$, where the length-weight exponent $b = 3.0989$ (Powell 1974).

Growth, as estimated from the model, was rapid during the first winter just after the fish immigrated into the estuary (5% increase in body weight per day; Table 2). Thereafter, even with increasing water temperatures, the instantaneous growth rate declined. At the end of spring (June), fish were growing at a rate approximating 0.02 (2% increase in body weight per day). At midsummer (August), the rate declined to 0.01 and almost no growth occurred during the fall and second winter of residency. Such a decline probably is determined by intrinsic rather than environmental factors, and frequently has been observed in other embryonic and postnatal animals (Laird et al. 1968). Growth resumed in early spring (April) but at a much slower rate (1% increase in body weight per day) and remained constant until yearlings moved from the sampling area, presumably to the ocean.

The lack of samples from March through May may limit the usefullness of the model in predicting early growth. A laboratory study by Peters and Angelovic (1973) suggests that little or no growth should occur at temperatures summer flounder encounter (Powell 1974) during their first 2 months of estuarine residency. If so, summer flounder would have to grow from 18 mm TL in April to 95 mm TL in June, a rate of 0.09 (9% increase in body weight daily). If adequate food were available, this rate could be attained (Peters and Angelovic 1973). Further studies on summer flounder growth should be directed towards the youngest fish. These studies would enhance the accuracy of a predictive growth model, and better our understanding of growth patterns.

Acknowledgments

References

CLOERN, J. E., AND F. H. NICHOLS. 1978. A von Bertalanffy growth model with a seasonally varying coefficient. Journal of the Fisheries Research Board of Canada 35:1479–1482.

ELDRIDGE, P. J. 1962. Observations on the winter trawl fishery for summer flounder, *Paralichthys dentatus*. Master's thesis. College of William and Mary, Williamsburg, Virginia, USA.

HETTLER, W. F. 1979. Modified neuston net for collecting live larval and juvenile fish. Progressive Fish-Culturist 41:32–33.

LAIRD, A. K., A. D. BARTON, AND S. A. TYLER. 1968. Growth and time: an interpretation of allometry. Growth 32:347–354.

LEWIS, R. M., AND W. C. MANN. 1971. Occurrence and abundance of larval Atlantic menhaden, *Brevoortia tyrannus*, at two North Carolina inlets with notes on associated species. Transactions of the American Fisheries Society 100:296–301.

PEARCY, W. G. 1962. Ecology of an estuarine population of winter flounder, *Pseudopleuronectes americanus* (Walbaum). III. Distribution, abundance, growth, and production of juveniles; survival of larvae and juveniles. Bulletin of the Bingham Oceanographic Collection, Yale University 18(1):39–64.

PETERS, D. S., AND J. W. ANGELOVIC. 1973. Effect of temperature, salinity, and food availability on growth and energy utilization of juvenile summer flounder, *Paralichthys dentatus*. Pages 545–554 *in* D. J. Nelson, editor. Radionuclides in ecosystems, proceedings of the third national symposium on radioecology, volume 1. National Technical Information Service, CONF-710501, Springfield, Virginia, USA.

POOLE, J. C. 1961. Age and growth of the fluke in Great South Bay and their significance to the sport fishery. New York Fish and Game Journal 8:1–18.

POOLE, J. C. 1966. A review of research concerning summer flounder and needs for further study. New York Fish and Game Journal 13:226–231.

POWELL, A. B. 1974. Biology of the summer flounder, *Paralichthys dentatus*, in Pamlico Sound and adjacent waters, with comments on *P. lethostigma* and *P. albigutta*. Master's thesis. University of North Carolina, Chapel Hill, North Carolina, USA.

POWELL, A. B., AND F. J. SCHWARTZ. 1977. Distribution of paralichthid flounders (Bothidae: *Paralichthys*) in North Carolina estuaries. Chesapeake Science 18:334–339.

RICKER, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

SHEPHERD, G. 1980. A comparative study of ageing methods for summer flounder (*Paralichthys dentatus*). United States National Marine Fisheries Service, Northeast Fisheries Center, Reference Document 80-13, Woods Hole, Massachusetts, USA.

SMITH, R. W., AND F. C. DAIBER. 1977. Biology of the summer flounder, *Paralichthys dentatus*, in Delaware Bay. United States National Marine Fisheries Service Fishery Bulletin 75:823–830.

SMITH, W. G. 1973. The distribution of summer flounder, *Paralichthys dentatus*, eggs and larvae on the continental shelf between Cape Cod and Cape Lookout, 1965–1966. United States National Marine Fisheries Service Fishery Bulletin 71:527–548.

TESCH, F. W. 1968. Age and growth. Pages 93–123 *in* W. E. Ricker, editor. Methods for assessment of fish production in fresh waters. International biological programme handbook 3. Blackwell Scientific Publications, Oxford, England.

WILK, S. J., W. G. SMITH, D. E. RALPH, AND J. SIBUNKA. 1980. Population structure of summer flounder between New York and Florida based on linear discriminant analysis. Transactions of the American Fisheries Society 109:265–271.

WILLIAMS, A. B., AND E. E. DEUBLER. 1968. A ten-year study of meroplankton in North Carolina estuaries: assessment of environmental factors and sampling success among bothid flounders and penaeid shrimps. Chesapeake Science 9:27–41.